MINOR INVESTIGATIONS IN SENSE PERCEPTION.

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I. ON DETERMINATIONS OF THE SUBJECTIVE HORIZON BY MOTOR CO-ORDINATION.

In the first volume of Harvard Psychological Studies which has recently appeared (Monograph Supplement 17, Psychological Review), an investigation concerning the subjective determination of the primary point of regard is reported by the present writer. In connection with that series of experiments an examination was made of manual and oculomotor co-ordination in such processes of spatial orientation. The relation of these factors in certain phenomena is well known. If the lateral axis of the head or the primary sighting-line of the eyes be not horizontal, the relations of the fundamental planes of space will be subject to distortion when these are determined by motor co-ordination of the hands. More specifically, if the head be tipped backward or forward, to one side or the other, the determination of horizontal lines in the plane of displacement will be negatively rotated. When the head is tipped toward the right, if one attempt to hold a bar in the two hands horizontally before the body and parallel with its lateral axis, the left end will unconsciously be depressed; if the tipping be toward the left, the right end of the bar will be depressed. These results are independent of the relation of the horizontal plane in which the line in question lies to that of the observer's eyes.

The problem to be determined in the experiments reported in the Harvard Psychological Studies concerned the factors of visual space orientation of this form under normal conditions, and the influence of unusual strains, positions of the body, and relations of external objects upon such determinations. Judgment was found to be affected by all of these, the movements and tensions of the eye-balls having the greatest influence. In connection with this investigation it became of interest to ascertain the relation of the subjective horizon of the eyes as determined by raising the index finger, to its position when determined visually, and the influence upon such location of changes in the orientation of the head and eyes.

The experimental arrangements of the previous investigation were maintained. Determinations of the horizon plane were made by the right index-finger in frontal and lateral vertical planes, the eyes being closed during the experiments, and the arm brought to a resting position in the lap between successive trials. The following experimental variations were to be tested. For determinations in both frontal and lateral planes, the position of the head being normal (a) locations with the eyes in their primary position; (b) locations with the line of sight elevated to the limit of unstrained adjustment; (c) locations with the line of sight similarly depressed. For determinations in the frontal plane alone—(a) locations with the head tipped upward and back; (b) locations with the head tipped forward and down. For determinations in the lateral plane alone:—(a) locations with the head tipped toward the right; (b) locations with the head tipped toward the left. Ten observers took part in the experiment. The individual averages of these were based upon series of fifty judgments each. The magnitudes of the angles of elevation and depression are given in degrees and fractions.

The results may be briefly summed. The plane of the subjective horizon under normal relations of body position is negatively rotated through a much greater angle than in visual determinations. The downward displacement increases from —7′.70 in locations made by the eye in a lighted room to —48′.9 in those made by manual co-ordination. It was found in the previous investigation that when the determination of the subjective horizon was made with closed eyes the line of sight was elevated to a point above the gravity horizon, the characteristic error being + 23′.69. The discrepancy between eye and hand is therefore to be reckoned thus much greater than the value of the absolute displacement, (48′.90 + 23′.69, or — 72′.59). The reason for this large error is to be sought in the normal co-ordination of these organs in the indication of positions in space. In pointing to any object the index-finger is habitually directed to a point below its actual location, in order that the line of vision may be left unobstructed. The free determination of the subjective horizon has thus reinstated the ordinary relations of eye and hand involved in simultaneous looking and pointing toward objects in that plane, and the characteristic error of location is therefore due finally to the anatomical relations of these two bodily members.

Determinations made with the line of sight of the closed eyes elevated (Experimental variation, I, b).) are marked by a negative displacement of large magnitude, the location now being,— 204′.40. The depression of the line of sight, on the other hand; (Exper. var., I, c).) is followed by no appre-

ciable displacement, the absolute location of the horizon, namely,— 49′.90, practically coinciding with that made under normal relations of the head. The difference in the results of these two forms of head rotation indicates apparently the significance of sensations of eye-movement and strain upon the process of localization. The degree of rotation in a bodily member is judged by the sensations of strain which develop in the course of its translation. As the curve of intensity in such experiences of strain exhibits a progressive acceleration with successive increments of angular movement, there arises the possibility of illusions of position and errors of estimation. In the present case the upward rotation of the eyes in their sockets develops a relatively intense strain experience, while in rotations of equal magnitude downward from the primary position of the eyes these muscular tensions are practically lacking. This difference arises from the biological relations of the organism to its environment, which call forth constant exploring movements of the eyes within the lower half of the field of vision, while very few are made above the horizon in the expanse of the sky. As a result of this discrepancy in the increment of strain, the over-estimation of the amount of rotation and consequent exaggeration of the corrective adjustment which appear in the one case are wholly absent in the other.

Results attributable to the same biological conditions appear when the whole head is rotated upward or downward. Upon the former movement follows a negative displacement of— 146′.50; upon the latter, a displacement of — 239′.40. When the chin is tilted upward, as was pointed out in the previous investigation, a reflex negative rotation of the line of sight takes place, which is practically lacking when the chin is dropped; the eyes move with the head in the latter case, while in the former they move independently of it and in the opposite direction. This downward rotation of the eyes does not involve noticeable sensations of strain; there exist, therefore, only the positive tensions of the supporting muscles of the head as factors of possible error in the first case, the effects of which appear in the negative displacement of the imaginary horizon. When the chin is depressed both systems of strain are reduced and there appears therefore a return to the normal co-ordination of hand and eye with a resultant large depression of the manually determined horizon, dependent upon the depression of the line of sight.

In all these cases the variability of the judgment is greatly increased over that of visual determination, the values of the mean variation being for rotations of the eyes:—normal, 55′.37; upward, 58′.80; downward, 56′.2; and for the head:— upward, 79′.80; downward, 60′.10. Every abnormality of

position also reduces the accuracy with which the judgment is reproduced. Of the two forms of bodily displacement compared in the present investigation the upward rotation of both eyes and head is marked by greater interference with the normal processes of judgment than movements in the opposite direction. This relation appeared also in visual determination of the horizon, and is to be looked for as a consequence of the different parts which these two forms of movement play in ordinary perception.

The attempt to bring the index finger to the level of the eyes and at arm's length from the side of the body results in the location of a point far below their true position, namely,—332′.80. Both negative and positive displacements of the line of sight in the closed eyes during the process of locating these points in the supposed horizontal plane of the eyes are followed by characteristic errors, a phenomenon which does not appear in the results of experiments on the determination of objective planes under like circumstances. Rotation of the head in its frontal or lateral plane does not affect the process of adjusting horizontally a bar which intersects that plane at right angles. In the present instance the upward rotation of the eyes gives a displacement of — 380′.1, or — 47′.3 from the normal; their downward rotation gives a displacement of — 300′.8, or + 32.0 from the normal. The direction of the error in both these cases is identical with the negative rotation of the subjective horizon which has been observed by other investigators to take place when the head is tipped in line with the points determined in that plane. As in the preceding experiments the greater correction accompanies upward, the less downward, rotation. The very large negative error which appears in these latter determinations is the result of the higher degree of muscular strain involved in bringing the arm up to the horizontal plane of the eyes at the side of the body as compared with frontal movements, and is not to be referred to any of the factors which are of interest in the present discussion. This error was not at all suspected by the reactors, and to the unforced character of the movements, with probably the additional factor of practice, is to be attributed the low index of variability which this series presents. The values are as follows:—normal, 46′.7; upward rotation, 53′.9; downward rotation, 49′.1. As before, the mean variation is greater in the case of upward than in that of downward rotation.

The last group of experiments, in which the head was rotated laterally, was not completed, and the results cannot therefore be given quantitatively. Enough was seen, however, of the influence of these experimental variations to show that their effects were to produce the characteristic errors of

location which appear when the attempt is made to hold a bar in a horizontal position under similar abnormal bodily positions.

The conclusions to which these experiments lead may be summed up briefly. These forms of spatial orientation are related to oculo-motor conditions, and the direction of the characteristic errors which they present are dependent upon the co-ordination of eye and hand in the perception reactions of ordinary practical life. The variations in amount of this constant error are related to simultaneous changes of direction and amount occurring in the tension of the oculo-motor mechanism, specific errors regularly taking the form of displacements of a sign negative to the direction of rotation in the eye-ball. The variability of the process of determination is a function of the intensity of strain which characterizes the primary movements of the head and eyes, and is therefore dependent upon the degree of interference with normal conditions of functioning which the latter involve. The characteristic errors appear to depend upon the objective displacement of the point of regard, interpreted on the basis of the organic strains involved in the various types of rotation, rather than upon the internal relations of these displacements to the principal planes of the body. since the location of the subjective horizon is equally affected by rotations in either of two planes at right angles to each other. With these determinants combine certain constant factors of resident strain in the organ, to give specific form to the judgment, but the consideration of these elements does not belong to the present discussion.

II. The Relation of Saturation in Homogeneous Colors to the Area over which the Color is Spread.

The apparent intensity of a stimulus, it has been noted in the case of various sensations, depends upon the magnitude of the area to which it is applied. When the whole hand is plunged into warm water, for instance, it feels hotter than when only the tip of the finger is immersed. If the taste of a substance in solution be too weak to produce any sensation of taste when only a small portion of the tongue is stimulated, its flavor may become clearly discriminable when a larger quantity is taken into the mouth. This reinforcement of the intensity of sensation by increasing the number of sensitive elements affected becomes our common practical method in the discrimination of faint odors.

It is a natural inference from the connection which is found in these instances that the number of elements of the sensitive surface stimulated and the intensity of the resulting sensation stand always in such a relation of functional dependence that

the subjective estimation of the intensity of a sensorial stimulus cannot be considered apart from the magnitude of the area excited.

In the case of certain senses it has been noted further that this summation effect is independent of continuity in the surface to which the stimulus is applied; intensive reinforcement takes place when the sensitive elements affected are not contiguous but form a discrete series. Thus in color vision if homogeneous light be distributed in the form of isolated spots of color the presentation of a sufficient group of these will give rise to a perception of their characteristic quality though the area of each individual unit be below the threshold of discriminability.

The small experiments reported in this paper concern two points in this general field; first, the quantitative relation of intensity to the number of elements stimulated in visual sensations arising from stimuli spread over continuous extents; and second, the quantitative relation of the stimulation area to the color threshold in continuous and discrete extents.

In studying the relation of saturation or color intensity to the area over which the color is spread three areas were compared, a unit of one square centimeter and two variables of four and sixteen square centimeters respectively. The series of six so-called pure saturated colors of the Bradley papers was employed. A double spindled color mixer was used, upon one shaft of which was mounted an unbroken disc of color, while upon that adjacent to it was mounted a combination of discs, including black and white as well as the color to be observed. In front of the revolving discs and just clear of their surfaces was stretched a screen of neutral gray paper, in which, near by each other, were cut two apertures having the areas of the unit and of the variable to be compared with it, respectively. Experiments were performed in indirect sunlight, the illumination coming from a point directly in front of the screen. The observer sat at a distance of one metre from the disc. Determination was made by immediate comparison of the saturation of the adjacent color areas, the record being made in terms of the angular magnitude of the color sector in the variable area, that of the unit being in all cases 360°. The work was obviously slow, since it was necessary to adjust the relative amounts of white and black in the neutral light introduced as well as the proportion of colored and uncolored light, in order that uniform brightnesses might be maintained between unit and variable areas. Two observers took part in the experiment; as the results in the two cases were parallel, only their averages will be given.

The proportions of colored light for each of the color qualities involved for the several areas are as follows:

	1 sq. c.	4 sq. c.	16 sq. c.
Red,–	360	342	318
Orange,–	"	295	270
Yellow,–	"	320	271
Green,–	"	282	261
Blue,–	"	341	324
Violet,–	"	298	240

The functional relation of the two factors appears in each of the two progressive variations introduced, and is exhibited by all members of the group of colors tested. In order to equalize the apparent saturation of two differing color-areas that of the larger must be reduced by the addition of a greater or less amount of uncolored light, varying according to quality and to the difference in magnitude of the areas. With progressive increase in the area of the colored surface the degree of apparent saturation likewise mounts. To what range of extents this relation applies, the present experiments do not show, since the greatest area included was still relatively small. The facts point toward the inclusion of all areas up to the limits of the total field of vision as thus affecting by their magnitude the saturation which the color presents; in other words a visual field all red or green is more vividly red or green than is any portion of that field seen amid neutral surroundings.

Since in the opposite direction the reduction of the retinal area stimulated, when carried to a certain point, results in the total disappearance of the color impression, we may say that the intensity of the latter is related throughout all its degrees to the area over which the stimulus is spread. It is not seen at its full intensity as soon as it is seen at all, but parallel with the enlargement of its area presents a series of intensive increments which at first are very rapid as the color area extends beyond the threshold, and afterward very slow; so that a spot of color just clearly discernible is scarcely less intense than the larger areas to which our ordinary experience is limited. The intensity of the color element in a given visual extent, however, is always less than that of any greater area having the same objective constitution, so that we should call only that color field fully saturated which extends to the whole field of vision.

The value of the differential factor of neutral light increases in the following color order: Red, Blue, Yellow, Violet, Orange, Green; in other words there is least difference in saturation between small and large areas of red, of all the colors observed, and most difference in the case of green. Therefore

the influence of the number of elements stimulated upon the intensity of the color sensation is greatest in the case of green, least in that of red. It will be recalled that in respect to energy these two colors form the opposite terms of the series (according to Langley's determinations), green possessing the greatest and crimson the least energy.

To the preceding series of experiments was added a set of observations on the relation of brightness intensities in neutral light when distributed over different areas. The phenomenon presented here is not the same as in the case of color, since in comparing neutral brightnesses the background is homogeneous in quality with the areas to be observed, in so far as it must possess the element of brightness. The so-called brightness is therefore virtually contrast with the gray background against which the area in question appears, and in reading the results one must estimate the various quantities as degrees of divergence in either direction from this zero-point.

The screen employed was that used in the preceding set of experiments; it corresponded approximately to a gray produced by the combination of black and white in the proportions, 270°, and 90°. In the series of brightnesses descending from this positive degree of illumination only one point was determined, while three were tested in the series ascending toward white, giving five combinations, having the following amounts of white in angular magnitudes: 0°, 90°, 180°, 270°, 360°. The proportions which gave equivalent subjective brightnesses for the three experimental areas are as follows:

1 sq. cm.	4″	16″		
0.0°	5.5°	9.7°	deg.	white.
90.0°	102.5°	90.0°	"	"
180.0°	189.5°	171.5°	"	"
270.0°	250.5°	241.5°	"	"
360.0°	315.0°	296.5°	"	"

In the first combination of the series the relations to be predicted are found to hold. The illumination of the experimental area in this case is less than that of the screen and its surface appears dark in contrast with the lighter gray background. The degree of this contrast increases with each increment of area; in other words, the darkness of the larger surface appears more intense both in the relation of the smaller variable to the unit and in that of the larger variable to the smaller. In the second combination of slightly weaker illumination than the background, and the third which was next above it, no definite direction of change is manifested, as might be expected. In the fourth and fifth of the group,—in both of which the illumination of the experimental areas was

distinctly greater than that of the background,—the dependence of contrast intensity upon area again appears definitely. It is to be observed that this influence increases in degree as the absolute difference between foreground and background grows greater. The amounts of black introduced in the several combinations give the following series of percentual values for the first and second variable areas respectively:

W 180	W 290	W 360	Area.
5.0 %	7.4 %	12.5 %	4 sq. em.
	10.7 "	17.7 "	16 " "

The figures present an approximation to the relations formulated in Weber's law, but it is questionable if a more extended series would continue the curve.

III. The Quantitative Relations of Stimulation Area and Color Threshold in Discrete as Compared with Continuous Extents.

In connection with a series of experiments upon the quantitative values of the color thresholds of homogeneous light, and of the visibility of such light qualities against colored backgrounds, it became important to compare quantitatively the color threshold depending upon a continuous extent of color with that arising from the distribution of the color in isolated spots over a larger field. It is the latter point only which is to be reported here.

The colors used and the conditions of lighting were as in the preceding experiments. Thresholds were tested for four colors only: red, blue, yellow and green; but to avoid inferential judgments some twelve qualities in all were used. The stimulation areas were controlled by means of sliding screens of dull, black-faced paper, so arranged as to present always a square. The observer sat a distance of six meters. The results are given in terms of square millimeters, and represent the average of five determinations. Two observers took part in the experiments.

The square area was first divided into two equal parts by a diagonal band of black, made successively two, five, and ten millimeters in width. With this arrangement determinations of red only for one observer, and of red and green for the other, were made. The results follow:

Obs.	Solid	2 mill.	5 mill.	10 mill.	
A.	48	35	30	15	Red.
B.	[1]160	116	120	78	Red.
	90	72	69	16	Green.

[1]The relations of absolute magnitude in the two observers, or in different colors, have no significance, since the determinations were made by daylight and only single series could be made under conditions of approximately constant illumination.

The area was next divided into four equal sub-areas by two diagonals having successively the widths of two, five and ten millimeters as before, with the following results:

Obs.	Solid	2 mill.	5 mill.	10 mill.	
A.	48	48	40	25	Red.
B.	160	145	99	40	Red.
	90	65	64	42	Green.

The stimulus was then distributed in the form of circular areas two millimeters in diameter, which were arranged in vertical and horizontal rows separated by successive distances of two, five and fifteen millimeters, with the following results:

Obs.	Solid	2 mill.	5 mill.	15 mill.	
A.	48	43	28	25	Red.
	94	18	15	12	Green.
B.	160	39	48	31	Red.
	90	25	37	28	Green.

Two other modes of distributing the stimulation-area were added to those already described, but as the results in each case were analogous to the preceding, they need not be repeated. The determinations of the thresholds for solid extents were made some weeks earlier than the rest of the results quoted. This may account for the great reduction of the threshold for red in B's results. Figures for blue and yellow are not given. Yellow could be discriminated (from white) only when a larger area was presented than could conveniently be arranged for with the apparatus used. The determinations of the thresholds for blue were very variable and unreliable on account of a similar constant confusion with black.

The quantitative relations presented by the tables may be stated in a word, since the same essential curve is exhibited by all. The maximum value of the threshold is reached when the color forms a solid extent. Its minimum value, within the range of conditions included in the present observations, is found when the area is sub-divided and its parts are most widely distributed over the retina. Between these two limits the value of the threshold increases and decreases as the constituent areas approach aggregation or depart from it. It appears then that color is most readily perceived not when it forms one continuous field but when it is distributed as separate patches within a larger area. An extent which is far below the limits of visibility under the former conditions may become clearly discriminable when it forms a group of smaller color spots. The influence of magnitude in the constituent areas is not so clearly shown as is the factor of separation among these parts.

If we abstract from the fact of local variations in the sensitiveness of the retina to color stimulation we should interpret the present results as indicating that any effect of reinforcement which the stimulation of individual points of the retina has upon the total effect produced is greater when these points are separated by unstimulated elements. If the important factor in such cases is the number of sensitive elements stimulated, and not the intensity of excitement aroused, the condition of distribution presents more favorable relations for perception than aggregation. The positive stimulation of any restricted portion of the retina affects also the adjacent unstimulated parts. The total irradiation effect thus produced must depend upon the proportion of stimulated points which are adjacent to elements not directly stimulated. This reaches its minimal value when the points immediately excited form a continuous extent. It would theoretically attain its maximum when each physiological unit was in isolation, but the practical limit may depend upon the co-operation of a variety of factors. This is sufficient to explain the results here presented.

It is possible that the phenomenon is due to an entirely different cause, namely the curve of color sensitiveness presented by a radial series of retinal points. The lowering of the threshold which follows upon dispersion of the stimulated points would then be dependent upon the increased sensitiveness of the elements stimulated under these conditions over that of the foveal area affected when the color formed a continuous extent. A definite curve for the color blue would have important bearing upon this point; but, as has already been stated, this set of tests was too variable to be depended upon.

NOTE. The observations collated in these two reports were made by Messrs. Bacon and Johnson, Davison and Phipps.